Atoms in Agriculture: A Study of Scientific Innovation between Technological Systems

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Abstract: This paper explores the nature of scientific research and innovation at the intersection of technological systems via a study of atomic age plant breeding. I show how the well-established framework of "large technological systems" can be deployed to understand research dynamics in the Cold War life sciences and further suggest that this framework might be useful in understanding still other areas of scientific research. I argue that the development of experimental tools and research programs dedicated to plant breeding via nuclear-derived technologies arose where researchers experienced the imperatives of innovation within two technological systems—nuclear and agricultural—simultaneously. In the absence of a significant infrastructure for nuclear agriculture, it was the mobility of innovations, the exchange of research tools and practices across experimental settings and research domains, which enabled nuclear-aided plant breeding to briefly flourish. As I show, understanding the dynamics of the technological systems in which researchers were embedded, including their interactions with other systems, is essential to understanding this unlikely area of research inquiry, the novel tools it relied upon, and the unusual scientific careers to which it gave rise.

Key words: atomic energy, agricultural experiment station, Brookhaven National Laboratory, Cold War, large technological systems, plant breeding, radiation genetics, T. S. Osborne, W. Ralph Singleton

Abbreviated title: Atoms in Agriculture

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The following abbreviations are used: AEC, Atomic Energy Commission (United States); AUI, Associated Universities, Inc.; BDO Files, Brookhaven National Laboratory, Director's Office Files, American Institute of Physics, College Park, MD; BNL, Brookhaven National Laboratory; DOE/NV, Department of Energy, Nuclear Testing Archive, Las Vegas, Nevada, www.osti.gov/opennet; LJS Papers, Lewis John Stadler Papers, State Historical Society of Missouri, Colombia, MO; NARA RG 326-G, Records of the Atomic Energy Commission, Photographic Prints, AEC Installations, Facilities, Personalities and Activities, 1947–72, U.S. National Archives and Records Administration II, College Park, Maryland; TAES, Tennessee Agricultural Experiment Station; UT, University of Tennessee; UT-AEC, University of Tennessee-Atomic Energy Commission; WRS Papers, W. Ralph Singleton Papers, Small Special Collections Library, University of Virginia, Charlottesville, VA.

In 1948 the University of Tennessee partnered with the U.S. Atomic Energy Commission in the creation of a new agricultural experiment station. Its founders hoped that the research conducted at this facility, located on the extensive grounds of the Oak Ridge Reservation not far from the Oak Ridge National Laboratory, would explore the use of radioisotopes in agricultural research and study the effects of radiation on agricultural production. In its early years, researchers stationed at this University of Tennessee-Atomic Energy Commission (UT-AEC) Agricultural Research Laboratory pursued topics ranging from the effects of atomic detonations on farm animals to the metabolism of fission products to radioisotope studies of egg and milk production. The research portfolio soon expanded to include plant investigations as well, including in particular efforts to breed new varieties through exposure to radiation.[1]

The UT-AEC facility, which I discuss in further detail below, brought together two outsized American technoscientific agendas of the later twentieth century: the promotion of nuclear technologies from within the growing American atomic infrastructure, and the expansion and industrialization of American agricultural production. Each exerted influence on the research programs and careers of those who worked there. In this paper, I chart the application of nuclear technologies in genetics research and plant breeding at sites like the UT-AEC laboratory in order to explore the nature of scientific research and innovation at the intersection of technological systems.

Historians of the life sciences have shown how the political imperatives of the Cold War shaped research in biology and ecology much as they did in physics and electronics. They have explained the flourishing of novel areas of research such as radioecology and nuclear medicine, and intensified interest in established fields like

[1] *UT-AEC Agricultural Research Laboratory* (Oak Ridge: UT-AEC, 1966).

human genetics, in the post-war years.[2] And they have explored extensively the development of new experimental tools contingent on the nuclear infrastructure, such as radioisotope tracers.[3] This historical work has convincingly demonstrated the

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[2] John Beatty, "Genetics in the Atomic Age: The Atomic Bomb Casualty Commission, 1947–1956," in *The Expansion of American Biology*, ed. Keith R. Benson, Jane Mainschein, and Ronald Rainger (New Brunswick: Rutgers University Press, 1991), 284–324; M. Susan Lindee, *Suffering Made Real: American Science and the Survivors at Hiroshima* (Chicago: University of Chicago Press, 1994); Toby A. Appel, *Shaping Biology: The National Science Foundation and American Biological Research 1945–1975* (Baltimore: Johns Hopkins University Press, 2000); Timothy Lenoir and Marguerite Hays, "The Manhattan Project for Biomedicine," in *Controlling Our Destinies*, ed. Phillip R. Sloan (South Bend: University of Notre Dame Press, 2000), 19–46; Angela N. H. Creager and María Jesús Santesmases, "Radiobiology in the Atomic Age: Changing Research Practices and Policies in Comparative Perspective," *Journal of the History of Biology* 39, no. 4 (2006): 637–47; Soraya de Chadarevian, "Mice and the Reactor: The 'Genetics Experiment' in 1950s Britain," *Journal of the History of Biology* 39, no. 4 (2006): 707–35; Alison Kraft, "Manhattan Transfer: Lethal Radiation, Bone Marrow Transplantation, and the Birth of Stem Cell Biology, ca. 1942–1961," *Historical Studies in the Natural Sciences* 39, no. 2 (2009): 171–218; Rachel Rothschild, "Environmental Awareness in the Atomic Age: Radioecologists and Nuclear Technology," *Historical Studies in the Natural Sciences* 43, no. 4 (2013): 492–530; Angela N. H. Creager, "A Cell-Based Epistemology: Human Genetics in the Era of Biomedicine," *Historical Studies in the Natural Sciences* 45, no. 1 (2014): 14–48.

[3] Angela N. H. Creager, *Life Atomic: A History of Radioisotopes in Science and Medicine* (Chicago: University of Chicago Press, 2013). See also Joel B. Hagen, *An Entangled Bank: The Origins of Ecosystem Ecology* (New Brunswick: Rutgers University Press, 1992), ch. 6; Stephen Bocking, "Ecosystems, Ecologists, and the Atom: Environmental Research at Oak Ridge National Laboratory," *Journal of the History of Biology* 28, no. 1 (1995): 1–47; Angela N. H. Creager, "The Industrialization of Radioisotopes by the Atomic Energy Commission," 141–67 in *The Science-Industry Nexus: History, Policy, Implications. Nobel Symposium 123*, ed. Karl Grandin, Nina Wormbs and Sven Widmalm (Sagamore Beach, MA: Science History Publications/USA, 2004); Angela N. H. Creager, "Nuclear Energy in the Service of Biomedicine: The U.S.

opportunities and rewards presented to those life scientists who pursued research trajectories aligned with national needs and interests during the Cold War.

My study of nuclear-related agricultural research follows in this vein, but further endeavors to show how these cases can be used to illuminate more general dynamics of research. Like others, I investigate how novel research topics and methods arose and expanded in the particular political and scientific climate of the Cold War, and the ways in which individual biologists (or indeed teams of scientists or institutions) responded to these changes. However, I also wish to use specific cases of life sciences research linked to Cold War politics to provide a model for understanding patterns of scientific innovation across different disciplines and institutions.[4] In doing so, I place equal

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Atomic Energy Comission's Radioisotope Program, 1946-1950," *Journal of the History of Biology* 39, no. 4 (2006): 649–684. On the global distribution of radioisotopes, see Jean-Paul Gaudillière, "Normal Pathways: Controlling Isotopes and Building Biomedical Research in Postwar France," *Journal of the History of Biology* 39, no. 4 (2006): 737–64; María Jesús Santesmases, "Peace Propaganda and Biomedical Experimentation: Influential Uses of Radioisotopes in Endocrinology and Molecular Genetics in Spain (1947–1971)," *Journal of the History of Biology* 39, no. 4 (2006): 765–94.

[4] A different approach to generalizing the dynamics of research in the life sciences and especially the creation of novel research technologies is Rheinberger's concept of "experimental systems." In the cases I examine here, experimental systems of the type Rheinberger describes can be seen as embedded within larger technological systems. Whereas Rheinberger charts the interactions among epistemic and technical objects within an experimental system, I am interested in the relationship between the emergence of things like experimental systems within the context of larger technoscientific infrastructures. On experimental systems, see Hans-Jörg Rheinberger, *Toward a History of Epistemic Things: Synthesizing Proteins in a Test Tube* (Stanford: Stanford University Press, 1997). For an application of the idea of experimental systems in a study of "nuclear agriculture," see Karin Zachmann, "Risky Rays for an Improved Food Supply? National and Transnational Food Irradiation Research as a Cold War Recipe," Preprint 7 (Munich: Deutches Museum, 2013), 8–10.

emphasis on the mechanisms at work within technological systems as on the national and international politics that set these in motion. I argue that the concept of large technological systems can be used to better understand research dynamics at the intersection of the life and physical sciences during the Cold War and that this suggests in turn how the framework of technological systems might be used to explore research at other similar intersections at different moments in history.

This argument rests on my observation that the development of experimental tools and research programs dedicated to plant breeding via nuclear-derived technologies appeared especially where researchers experienced the imperatives of innovation arising from two distinct technological systems. On the one hand, the nuclear system encouraged research programs and experimental tools that would make use of expensive and expanding infrastructure; its administrators also hoped for innovations that would advertise the clear benefits of this system to all Americans, scientists and non-scientists alike. On the other hand, the agricultural system demanded innovations that would keep the increasingly entrenched mode of industrial production moving forward at a fast clip; for breeders this meant producing new varieties of commodity crops that would be more suited to the constraints of large-scale mechanized agricultural production. At sites like the UT-AEC Agricultural Research Laboratory, where nuclear and agricultural interests were each represented, employees were likely to feel the pressure of appealing to both simultaneously.

In what follows, I consider the use of nuclear technologies in plant breeding at two American institutions. I look first to the biology department of Brookhaven National Laboratory, where a group of biological researchers innovated tools for plant irradiation, and began in the 1950s to share these with nearby agricultural researchers through a cooperative plant irradiation program. I then explore similar efforts undertaken at the UT-AEC Agricultural Research Laboratory in Oak Ridge, Tennessee, focusing in particular on how these were shaped by their more immediate agricultural context. Together these cases suggest the potential for historians of the life sciences, and indeed historians of science in general, to use the concept of large technological systems as means of studying both site-specific research dynamics and large-scale trends. I develop in the conclusion a further argument that both historians of science and historians of technology ought to pay closer attention to intersections of technological systems that do not become permanent infrastructures, for these may provide a rich picture of novel science and technology thriving in the new and sometimes unique research spaces created at such intersections.

[FIRST LEVEL HEADING] INNOVATION AND THE ATOM

The late-nineteenth and twentieth centuries saw the development of what historians of technology have labelled "large technological systems" in domains ranging from energy production and distribution to communication to transportation. Such systems are characterized by a daunting array of interworking parts, which include not only material technological artifacts (in the case of energy production, these would be objects such as coal-fired power plants, transmission wires, home electrical outlets) but also organizations (commercial energy suppliers, equipment manufacturers, government regulatory bodies) and knowledge (physics textbooks, electrician certification programs) and perhaps still other elements, all of which operate in conjunction with one another and are oriented towards the same end goal (the delivery of electrical power).[5]

The historian Thomas Hughes contends that one significant feature of such systems, besides their size, is that they tend to foster innovations that perpetuate the system. This notion was informed by Hughes's observation of the development of electrical power networks. Once significant social and economic investments in an electric power station and grid were made, it became difficult to propose technical changes that would disrupt operation or entail costly redesign of other components, even if such innovations would be mechanically more efficient, provide greater safety, or offer some other advantage. More acceptable innovations were those that straightforwardly allowed for continued production, or extension of the system. Particularly desirable were innovations that enabled greater consumption of electricity by end users, thereby creating demand for greater power production.[6]

It is possible to consider this phenomenon on a still larger scale, with reference to atomic energy in the post-war decades of the twentieth century. Working from Hughes's example, one might guess that once a costly national infrastructure for producing atomic energy and other atomic products was in place, it would become increasingly relevant and important for institutions and individuals within that system to generate and use technologies that relied on its key product—atomic energy. And this is what historical

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[5] Thomas Hughes, "The Evolution of Large Technological Systems," in *The Social Construction of Technological Systems*, ed. W. E. Bijker, T. P. Hughes, and T. J. Pinch (Cambridge: MIT Press, 1987), 51–82.

[6] Thomas Hughes, *Networks of Power: Electrification in Western Society, 1880–1930* (Baltimore: Johns Hopkins University Press, 1983). Hughes often referred to "conservative" versus "radical" innovations in part to explain this phenomenon; I avoid these terms because Hughes used these to capture still other aspects of innovation within systems that are not relevant to this article.

research on a range of nuclear science programs suggests. Many various means of consuming atomic energy were developed (or redesigned or newly promoted) within the American nuclear technological system, especially during its early decades. Atomic weapons, nuclear submarines, domestic power stations, earthmoving technologies, radiation therapies, radioisotopes for experimental use—even seed-irradiation units for plant breeders—these were all artifacts generated within a technological system, and many were used to provide grounds for its continued existence. The atomic infrastructure encouraged, and produced, atomic innovations.[7]

With this overview in mind, I turn now to a specific example, in order to show in practice how and why a variety of scientific innovations, including new tools, new methods, and new subjects of research, could emerge from the demands of the nuclear technological system as a whole. The example is the use of radiation in plant biology and plant breeding at Brookhaven National Laboratory in the 1940s and early 1950s. This particular research initiative did not emerge within the vast sprawling infrastructure of later decades but instead developed early on, within the still-nascent nuclear system. By the end of 1948, this system comprised mostly the initial wartime nuclear installations and a new laboratory (Brookhaven) on Long Island that fell under direct AEC control—the beginnings of a network of national research laboratories that the historian Peter Westwick has described as a system all its own—as well as a growing number of AEC-

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[7] The early development of the U.S. nuclear infrastructure is chronicled in the official histories of the AEC: Richard G. Hewlett and Oscar Edward Anderson, *The New World, 1939–1946* (University Park: Pennsylvania State University Press, 1962); Richard G. Hewlett and Francis Duncan, *Atomic Shield, 1947/1952* (University Park: Pennsylvania State University Press, 1969); Richard G. Hewlett and Jack M. Holl, *Atoms for Peace and War, 1953–1961: Eisenhower and the Atomic Energy Commission* (Berkeley: University of California Press, 1989).

funded military and other research programs at outside institutions.[8] Though young, this system proved fertile ground for innovation.

Brookhaven was launched in the immediate post-war years, with the goal of making available to researchers in the American Northeast some of the impressive new technologies of nuclear science. It was envisioned as a home especially for expensive, large-scale projects—things like accelerators and reactors—and for cooperative research that would reach across institutions. The latter feature was considered especially important. The use of the unique nuclear technologies by individuals not employed at Brookhaven would justify the enormous government expenditures needed to create another nuclear facility.[9]

From the start, the laboratory included life sciences programs alongside its physical sciences and engineering works. Brookhaven administrators expected that biologists working at the laboratory would cleave closely to the nuclear research agenda, not least by making use of the more unique tools the laboratory had to offer. At the outset, they envisioned investigations in three broad areas: the biological effects of radiation, the investigation of biological pathways using radioisotopes, and the development of general methods for using nuclear technologies in biological research.[10] As the chairman of the biology department Leslie Nims described in 1947 at a conference showcasing life sciences research opportunities at Brookhaven, the

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[8] Westwick characterizes the national laboratories as an "institutional system," along the lines of a technological system. See Peter Westwick, *The National Labs: Science in an American System, 1947–1974* (Cambridge: Harvard University Press, 2003), 7.

[9] On the early history of Brookhaven, see Robert P. Crease, *Making Physics: A Biography of Brookhaven National Laboratory, 1946–1972* (Chicago: University of Chicago Press, 1999).

[10] Ibid., 63.

biological research program aimed not only to develop safe, exportable methods for using radioactive tracers in biological research, but also to invite cooperating researchers to do work at Brookhaven because "[t]he 'pile' will make many short lived isotopes which will have to be studied nearby." Studies of radiation effects would also rely on the novel resources of the laboratory: the pile could also be used to study "neutron effects" and, as Nims emphasized, "We will have intense sources of neutrons, alpha, beta and gamma rays as well as other forms of radiation."[11] In other words, innovations generated for or as a by-product of physics research—things like reactors, radioisotopes, and other radiation-generating objects—were to be key resources for the biologists as well.

These research priorities appear to have been non-negotiable. For example, in 1948, the maize geneticist and breeder W. Ralph Singleton was offered one of the department's senior research positions. Like other senior hires, Singleton was given leave to devise his own experimental program; however, the chairman of the biology department made it clear that the research should involve radiation and, ideally, radiation that relied on the technologies available at Brookhaven. When Singleton submitted an initial set of ideas on maize genetics, Nims encouraged a revision that would involve "either radiation or tracer experiments." He suggested in particular that at least some of the maize seed should be "judiciously exposed to x-rays."[12] Singleton assented, adding a treatment of radiation to the first experimental plan.[13] Pleased by the

[11] L. F. Nims, "Opportunities in Biological Research," *Brookhaven Conference Report: Biology and Medicine* (Upton, NY: Brookhaven National Laboratory, 1947), 3–4.

[12] Nims to Singleton, 9 Mar 1948, WRS Papers, Box 5.

[13] Singleton substituted UV-radiation for x-rays because he knew this to be more useful in producing genetic mutations in maize. Singleton to Nims, 12 Mar 1948, WRS Papers, Box 5.

change, Nims reminded Singleton that the following year neutron radiation would also be available through the nuclear reactor and the particle accelerator, two laboratory facilities still under construction.[14]

Singleton not only matched Nims's expectations for a research program based on the novel research tools at Brookhaven, he soon bettered them. Within a year, he was collaborating on entirely new methods and technologies for studying the biological effects of radiation. Singleton's first effort to pioneer methods was his collaboration in the development of the Brookhaven gamma field, a large plot in which various biologists could monitor the effects of chronic gamma irradiation on plants. In its initial instantiation, the gamma field comprised a piece of cleared agricultural land with a 16-curie radioisotope of cobalt-60 at the center. This radioisotope was encased in a stainless steel pipe and could be raised (through the pipe) to a position ten feet above the ground. The idea was that the cobalt-60 would emit constant radiation, primarily gamma rays, which would continuously bombard the specimens planted in the field. Plants grown in the field would be exposed to different amounts of radiation, depending on how far they had been planted from the central radiation source.[15] (Figures 1 and 2.)

[Figure 1 about here.]

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[14] Nims to Singleton, 19 Mar 1948, WRS Papers, Box 5. For a discussion of the various ways in which nuclear technologies were to be incorporated into the research program of the Biology Department, see Brookhaven National Laboratory, "Annual Report, July 1, 1950," (Upton, New York: Associated Universities, Inc., 1950), 68–70.

[15] See descriptions in W. Ralph Singleton, *Nuclear Radiation in Food and Agriculture* (Princeton: Van Nostrand, 1958), ch. 26; Arnold H. Sparrow and W. Ralph Singleton, "The Use of Radiocobalt as a Source of Gamma Rays and Some Effects of Chronic Irradiation on Growing Plants," *American Naturalist* 87, no. 832 (1953): 29–48.

[Figure 2 about here.]

For all its simplicity, the gamma field represented a novel experimental approach within a well-established field of research. Until its creation, experimental studies of radiation effects on plants and animals had for practical reasons focused primarily on acute irradiation, such as short exposures to radiation produced by an x-ray machine or a cyclotron. These were, by necessity of the amount of electrical energy required, of relatively short duration. Chronic exposure could have been achieved through the use of radium, a continuous emitter of gamma radiation, except that radium was prohibitively expensive. It had been used in small-scale studies on plant life, especially in the earlier decades of the twentieth century, but it was not suitable for studies that were both large-scale and long-term.[16] These conditions changed with the expansion of nuclear physics during and after World War Two, in particular with the proliferation of technologies that produced, whether intentionally or as by-products, radioactive elements. As historians have charted, the production of radioisotopes after the war, undertaken and heavily subsidized by the U.S. government through the AEC, influenced biological research across the United States and around the world. The production and distribution of radioisotopes is well known to have fostered new areas of medical, biological, and ecological research in the postwar years.[17] One atomic innovation (the conversion of wartime facilities to the mass production of radioisotopes) spawned myriad innovations in research in diverse disciplines.

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[16] There was greater knowledge relating to long-term or chronic human exposures to radiation such as that seen among workers using radium paints. On the history of radiation safety, see J. Samuel Walker, *Permissible Dose: A History of Radiation Protection in the Twentieth Century* (Berkeley: University of California Press, 2000).

[17] Creager, *Life Atomic* (ref. 3). See additional sources in ref. 3.

This process was plainly evident in the gamma field. In 1948, with artificial radioisotopes more readily available, previously impossible large-scale studies of chronic irradiation could be undertaken. One could think of generating long-term exposures under field conditions as opposed to in laboratory spaces, and over much longer periods of time. Because such studies had not previously been done, Singleton and the other Brookhaven biologists could claim to be pursuing path-breaking research into the study of radiation effects on plants despite the fact that this was by the late 1940s a well-tilled field of inquiry. Newly available atomic tools enabled them to devise novel experimental setups and forge new research agendas around these.[18]

Singleton's research in the gamma field, which considered the effects of chronic irradiation of maize, quickly led him to other research proposals. When he was hired, he had expressed skepticism about using highly energetic radiation in his research program even as he agreed to it. In 1948, he maintained that x-rays only generated chromosomal changes, "translocations and inversions and deletions," and not the more sought-after changes in genes, or "point mutations."[19] But his research at Brookhaven evidently led him to reconsider—in fact, to do an abrupt about-face. As a result of his initial studies in the gamma field, which suggested that the rate of mutation in maize increased as a result of exposure to gamma rays, Singleton came to believe not only that gamma rays would induce the desired gene mutations but that they might in fact induce useful mutations, and perhaps even be turned into a tool for breeders.

[18] Sparrow and Singleton, "Use of Radiocobalt" (ref. 15), 29.

[19] This was an assumption apparently shared by most plant geneticists at the time, not least because cytological analyses showed gross physical alteration to chromosomes following irradiation. Singleton to Nims, 12 Mar 1948, WRS Papers, Box 5.

The premise behind this last idea was simple: if genetic mutations were the source of the variations that plant breeders used in developing new varieties, then surely a technology that produced mutations in abundance could be a useful tool for plant breeding. His innovation in atomic research might also be an innovation useful in agricultural production, as a means of generating new crop varieties.[20] Singleton knew well the constraints and ambitions of plant breeding and the potential power of a technology that could generate variation on demand. For more than twenty years he had worked at the Connecticut Agricultural Experiment Station, where he had gained much greater notoriety for his varieties of sweet corn than for his studies in maize genetics.[21] And from his vantage point at Brookhaven, he was no doubt equally well aware of the rewards that might accrue to a researcher putting nuclear science to use in such a dramatic way.

Singleton first thought he might pursue the aim of demonstrating the use of nuclear technologies in plant breeding via his own research, attempting to induce a desirable gene for short stature in maize. This idea had arisen from his prior work at the Connecticut Agricultural Experiment Station, where in the 1940s he had discovered a

[20] The influence of radioisotopes on agricultural research is less well documented than on other areas of research. One exception is food irradiation; see, e.g., Nicholas Buchanan, "The Atomic Meal: The Cold War and Irradiated Foods, 1945–1963," *History and Technology* 21, no. 2 (2005): 221–49; Karin Zachmann, "Atoms for Peace and Radiation for Safety – How to Build Trust in Irradiated Foods in Cold War Europe and Beyond," *History and Technology* 27, no. 1 (2011): 65–90; Zachmann, "Risky Rays" (ref. 4). An article which offers the AEC perspective on the use of radioisotopes in agricultural research is Neil Oatsvall, "Atomic Agriculture: Policymaking, Food Production, and Nuclear Technologies in the United States, 1945–1960," *Agricultural History* 88, no. 3 (2014): 368–87.

[21] e.g., "Local Station Finishes Work on New Corn," *New Haven Journal Courier*, 14 July 1939.

mutation in sweet corn that produced shorter-than-normal plants. These could be hybridized with traditional types to create plants about six-feet tall instead of the typical fourteen-feet.[22] Singleton claimed that the short corn plants were more efficient to cultivate, especially in terms of the amount of fertilizer they needed. The application of this discovery was limited, however, as incorporating the genetic trait into the many different lines of inbred corn then in cultivation via traditional methods would be "laborious and time consuming," to quote Singleton. He thought that radiation could potentially provide an end-route around this labor, for "if [the short-gene] can be induced by continuous γ [gamma] radiation it could be done more quickly."[23]

In late 1951, Singleton further proposed that some of the gamma field be given over to studies of somatic mutations in fruit trees, evidently thinking this might be a route to the faster production of potentially useful variations in fruit crops.[24] But this work was not to be conducted by Brookhaven employees. Instead plans took shape for a cooperative program that would engage scientists beyond Brookhaven. In December 1952, the biology department invited researchers from the United States Department of Agriculture (USDA) and agricultural institutions on the east coast to a conference at which the possibilities for collaboration were explored. The conference quickly led to an official cooperative program.[25] Launched in the spring of 1953, the program brought together the nuclear technologies of Brookhaven and the expertise of agriculturalists stationed elsewhere, in order to evaluate "the feasibility of producing useful mutations

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[22] "Scientist Converts Tall Field Corn into Short for Easier Harvesting," *New York Times*, 27 Aug 1948.

[23] Singleton, "Progress Report," 23 June 1950, WRS Papers, Box 6.

[24] Singleton, "Progress Report," 28 Dec 1951, WRS Papers, Box 6.

[25] See letters of invitation, e.g., Curtis to Deering, 19 Nov 1952, BDO Files, Reel 9, Folder 10.

in plants by means of ionizing radiations" that would use both the gamma field and other radiation facilities.[26]

The program, sometimes referred to as the "radiations mutation" program, focused initially on the production of somatic mutations in trees and shrubs, which could easily be propagated asexually. Collaborating researchers were invited in most cases to have plants placed in the gamma field by the Brookhaven staff, where they would be cultivated for one or several seasons before being removed and returned to for continued growth and observation. The program quickly expanded, and not just in terms of participant numbers. Brookhaven soon offered agricultural collaborators the additional option of seed and pollen irradiation, treatments intended to create genetic mutations. And they created opportunities to use other radiation sources, such as the nuclear reactor (via its "thermal column"), which served as a tool for thermal neutron irradiation or the "gamma radiation greenhouse" for more localized radiation treatments than the gamma field allowed.[27] (Figure 3.) These innovations, useful for in-house research among biologists at a nuclear facility, were transformed via the radiations mutation program into tools for research among a much larger community of agricultural experimenters.

[Figure 3 about here.]

The cooperative radiation mutations program was popular with outside researchers, to judge by the program's early and rapid expansion.[28] Perhaps more

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[26] BNL, "Annual Report, July 1, 1953," (Upton: AUI, 1953), 44.

[27] Seymour Shapiro, "The Brookhaven Radiations Mutation Program," in *A Conference on Radioisotopes in Agriculture* (East Lansing: U.S. AEC, 1956).

[28] A list of cooperating institutions and species irradiated through 1954 can be found in Curtis to Tape, 4 Feb 1955, BDO Files, Reel 9, Folder 11.

important, it was popular with Brookhaven administrators, for its success indicated that the laboratory was achieving its goal of providing unique facilities that attracted researchers from across the Northeast. The 1954 annual report of the laboratory, which emphasized the expansion of collaborative research ("one of the original objectives in establishing Brookhaven National Laboratory"), included the gamma field as one of its four major cooperative facilities alongside the facilities for which Brookhaven was (and is) far better known—the cosmotron, the cyclotron, and the nuclear reactor.[29] (Figure 4.) The report proudly boasted that the plant breeding program, "conducted in conjunction with 17 universities and agricultural experiment stations," was dominating activities in plant physiology: "Almost half the gamma field is now being utilized for this project, and nearly half the time of the thermal column."[30] Although it was not one of the atomic research technologies initially envisioned for this peacetime national laboratory, the gamma field fit right in among its other, more expensive and technologically complex, facilities.

[Figure 4 about here.]

If the radiations mutation program was a good fit for the laboratory—a means of promoting cooperative peaceful nuclear research centered around unique, large-scale research facilities—it was also an excellent fit within a larger system. The specific institutional context that encouraged the development of the cooperative induced-mutation research at Brookhaven, and with it interest in using radiation in plant breeding, was itself a product of a growing technological system directed at securing and advancing U.S. nuclear capacities. Within this system, the radiations mutation

[29] See foldout in BNL, "Annual Report, July 1, 1954," (Upton: AUI, 1954).

[30] Ibid., 49.

program at Brookhaven and its associated technologies came to play an important role: like other areas of medical or life sciences research, they were offered as evidence of the American government's good faith effort to develop atomic energy's more productive capacities alongside its destructive ones.

As a number of historians have described, the considerable involvement of the AEC in the life sciences served a political function much as it advanced knowledge about radiation or the intellectual agendas of the scientists the commission supported. Because physics-related research seemed inextricable from the production of weapons, biological and biomedical research were the key focal points for government claims to using atomic energy as a tool for social good.[31] Therefore the AEC and the institutions it sponsored advertised their life sciences research programs—including the radiation mutations program—through speeches, news reports, conferences, traveling exhibits, and more. Their aim was to convince politicians and the general public of the better world the commission was working to achieve, and especially to keep money and resources flowing toward the development of the atomic infrastructure.[32] These

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[31] John Beatty, "Scientific Collaboration, Internationalism, and Diplomacy: The Case of the Atomic Bomb Casualty Commission," *Journal of the History of Biology* 26, no. 2 (1993): 205–31; Angela Creager, "Tracing the Politics of Changing Postwar Research Practices: The Export of 'American' Radioisotopes to European Biologists," *Studies in History and Philosophy of Science Part C: Studies in History and Philosophy of Biological and Biomedical Sciences* 33, no. 3 (2002): 367–88; Angela Creager, "Radioisotopes as Political Instruments, 1946-1953," *Dynamis* 29 (2009): 219–39; John Krige, "The Politics of Phosphorus-32: A Cold War Fable Based on Fact," *Historical Studies in the Physical and Biological Sciences* 36, no. 1 (2005): 71–91.

[32] On publicity efforts by the AEC, see Spencer Weart, *Nuclear Fear: A History of Images* (Cambridge: Harvard University Press, 1988), ch. 8; Martin J. Medhurst, "Atoms for Peace and Nuclear Hegemony: The Rhetorical Structure of a Cold War Campaign," *Armed Forces & Society* 23, no. 4 (1997): 571–93; A.

activities, already underway in the early postwar years, expanded with articulation of an official government agenda for promoting “peaceful uses” of atomic energy. In December 1953 President Dwight Eisenhower addressed the General Assembly of the United Nations (UN) to propose “Atoms for Peace, ” a plan for the distribution of nuclear materials to researchers around the world in order to “apply atomic energy to the needs of agriculture, medicine, and other peaceful activities.”[33] Eisenhower and his advisors intended among other things for Atoms for Peace to distract attention from the U.S. commitment to weapons development and testing. Efforts were soon underway to aggressively promote the positive sides of nuclear development nationally and internationally.[34]

The radiations mutation program at Brookhaven easily aided this political agenda within the United States. To take just one of many examples, Singleton was invited in the spring of 1954 to participate in congressional hearings on the uses of atomic energy in agriculture. As he was reminded in his instructions, these open hearings were "to be printed and distributed to the public."[35] In other words, they were to be part of the AEC's ongoing campaign to highlight clear benefits of nuclear science

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Constandina Titus, “Selling the Bomb: Public Relations Efforts by the Atomic Energy Commission During the 1950s and Early 1960s,” *Government Publications Review* 16, no. 1 (1989): 15–29.

[33] Eisenhower, Address to the 470th Plenary Meeting of the United Nations General Assembly, 8 Dec 1953. http://www.iaea.org/About/history_speech.html (accessed 26 Apr 2011).

[34] Krige identifies still other purposes, such as the redirection of Soviet nuclear capabilities to the international program and circumscribing the development of nuclear capabilities in other countries to include only energy production and other non-military activities. See John Krige, “Atoms for Peace, Scientific Internationalism, and Scientific Intelligence,” *Osiris* 21 (2006): 161–81, on 162–63. On Atoms for Peace in relation to food and agricultural research, see Zachmann, “Risky Rays” (ref. 4).

[35] Pearson to Singleton, 8 Mar 1954, WRS Papers, Box 7.

and technology.[36] In his presentation, Singleton went above and beyond in pursuit of this aim, predicting that "the science of radiation genetics will soon become one of the most important events in the history of agriculture."[37] By way of explanation, he discussed the use of neutron radiation at Brookhaven to create rust-resistant oats, a success achieved in one-and-a-half years and at "a very small cost" that "would have taken at least 10 years by conventional plant breeding methods, at considerable expense," and he further indicated that this was only the tip of the iceberg.[38] Singleton declared that plant breeders were "on the verge of a new era" thanks to the increased production of radioisotopes and other forms of atomic radiation and to the research programs that put these to use—ideas that would be echoed often by AEC officials in the months and years that followed.[39]

Investment in nuclear science and technology had created the initial opportunity for interest in breeding programs that relied on radiation. The atomic-age approach to breeding in turn promised to bolster support for on-going investment in nuclear science and technology—that is, for investment in and expansion of the entire technological system. And as that system continued to grow, it created still more opportunities for the as-yet unproven methods of nuclear-aided plant breeding to gain a foothold.

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[36] The Contribution of Atomic Energy to Agriculture: Hearings before the Subcommittee on Research and Development of the Joint Committee on Atomic Energy, Congress of the United States, Eighty-third Congress, second session, 31 March and 1 April, 1954.

[37] Statement of Ralph Singleton in The Contribution of Atomic Energy to Agriculture (ref. 36), 43.

[38] Ibid., 44–45.

[39] Ibid., 55. For an example of an address by an AEC official along these lines, see e.g., Willard F. Libby, "The Economic Potential of Radioisotopes in Agriculture," in *A Conference on Radioactive Isotopes in Agriculture, 12–14 January 1956, East Lansing, Michigan* (Washington: U.S. AEC, 1956), 5–6.

[FIRST LEVEL HEADING] INNOVATION IN AGRICULTURE

In the 1950s, under the influence of the AEC and with the interest and enthusiasm of a number of plant breeders, a recognizable field of "mutation breeding" took shape in the United States. More research programs were established, more conferences held, more tools developed. Many breeders who worked with radiation in the atomic age recognized that the resurgence of interest in this area was not primarily driven by new discoveries about its usefulness. They pointed instead to the sharp rise in access to radioactive materials and nuclear technologies. As a representative of the Food and Agriculture Organization (FAO) of the United Nations described in 1958, "With the development of atomic energy other types of radiation became freely available for experimental use, so that there has recently been a general upsurge of interest in the possibility of putting radiation to practical use in crop breeding."[40] Of course, it was more than access to tools that mattered. It was the whole of the expanding nuclear technological system—with all its material, social, and intellectual components—that encouraged the development and use of nuclear technologies by plant breeders in the early Cold War period. That, after all, is what rewarded mutation breeders (as they well knew) for their stated interest in making nuclear technologies into effective tools of genetic manipulation. And the rewards that existed within this system for early pioneers like Singleton were heightened still further with the expansion of Atoms for Peace activities in the mid-1950s both in the United States and beyond. Although it began as a

[40] R. A. Silow, "The Potential Contribution of Atomic Energy to Development in Agriculture and Related Industries," *International Journal of Applied Radiation and Isotopes* 3 (1958): 257–80, on 266. Other examples include Calvin F. Konzak, "III. Genetic Effects of Radiation on Higher Plants," *Quarterly Review of Biology* 32, no. 1 (1957): 27–45, on 27; Sparrow and Singleton, "Use of Radiocobalt" (ref. 15), 29.

piece of American political and military strategy, as the historian Karin Zachmann describes, Atoms for Peace "quickly grew, developing a dynamic of its own" and moving beyond the control of its American originators.[41] Mutation breeding benefitted from this changed dynamic, capturing the attention of researchers and institutions around the world.[42]

But nuclear concerns were not the only ones to encourage greater interest in this area of research. Important, too, was its appeal to strongly felt needs within another technological system: agricultural production. Breeders needed to keep up with the constant appearance of new agricultural pests and diseases, problems that seemed to be exacerbated by the methods of modern industrial agriculture. Mono-cropped fields of inbred varieties were especially susceptible to disease outbreaks. Furthermore, as farmers applied new chemical insecticides, insect populations developed greater resistance to these as a result of selective pressure. Ditto for herbicides and weeds. What breeders needed, and the induced mutation researchers promised, was a tool that would outpace this kind of evolutionary change. As the Brookhaven biologist Harold Smith summarized, "It may even be necessary to speed up the controlled evolution of organisms vital to our existence in view of the rapid alterations that humans are causing… Consider, for example, the increasing menace from pathogenic organisms

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[41] Zachmann, "Risky Rays" (ref. 4), on 7.

[42] Ibid. See also Jacob Darwin Hamblin, "Let There Be Light… and Bread: The United Nations, the Developing World, and Atomic Energy's Green Revolution," *History and Technology* 25, no. 1 (2009): 147–77; Jacob Darwin Hamblin, "Quickening Nature's Pulse: Atomic Agriculture at the International Atomic Energy Agency," *Dynamis* 35, no. 2 (2015): 389–408; and Karin Zachmann, "Peaceful Atoms in Agriculture and Food: How the Politics of the Cold War Shaped Agricultural Research Using Isotopes and Radiation in Post War Divided Germany," *Dynamis* 35, no 2. (2015): 307–331.

attacking crop plants when relatively homozygous genotypes, as of wheat, are grown over large areas."[43] In this vision, articulated here by a plant geneticist employed at a nuclear facility, the use of nuclear technologies to induce mutation was a process ideally suited to meet the challenges created by modern, chemical-laden, monocropped agricultural production of highly inbred crops.[44] Many of his peers at more traditional agricultural research institutions hoped this would indeed be the case.

If looking at the cooperative radiations mutation program at Brookhaven provides insight into how and why some areas of agricultural research were brought into the national system for nuclear research and development, taking a look at the application of radiation to plants at the UT-AEC Agricultural Research Laboratory reveals how nuclear technologies became a part of the established U.S. agricultural research system. As I described in the introduction, this research facility had been created as a joint endeavor of the AEC and the University of Tennessee. The laboratory, dedicated to the application of nuclear science and technology to agricultural research, was to be run by the university as a new branch of the Tennessee Agricultural Experiment Station (TAES).

State agricultural experiment stations, like the several branches that formed the TAES, number among the oldest federally funded research institutions in the United States. From the late nineteenth century, they played a key role in the maintenance of

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[43] Harold H. Smith, "Radiation in the Production of Useful Mutations," *Botanical Review* 24, no. 1 (1958), 1–24, on 3.

[44] Other instances of this include: BNL, "Annual Report, July 1, 1954," (ref. 29), 51–52; Libby, "Economic Potential (ref. 39), 5.

American agricultural productivity.[45] They were, however, only one of many institutions and activities dedicated to this central aim. The infrastructure for agricultural production in the United States—which included research stations, commercial producers, farm equipment, agricultural knowledge, and so on—might like the atomic infrastructure be considered a large technological system, in this case one aimed at the mass production and distribution of agricultural commodities.[46] And this system, too, tended to foster or produce innovations that facilitated large-scale, intensive cultivation of commodity crops and their efficient dispersal, rather than radical, potentially system-changing, ones. Examples include the creation of ever-larger and more efficient harvesting machines, the proliferation of technologies for preserving, packaging, and transporting farm commodities, the adoption of plants bred to facilitate mechanical harvesting and to survive long-distance distribution, and the prophylactic use of antibiotics on factory-style farm operations, among others.[47] It is perhaps no surprise,

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[45] On the early history of agricultural experiment stations, see Charles E. Rosenberg, *No Other Gods: On Science and American Social Thought*, rev. ed. (Baltimore: Johns Hopkins University Press, 1997 [1976]), ch. 9–12. Works that document this history well into the twentieth century include: Norwood Kerr*, The Legacy: A Centennial History of the State Experiment Stations, 1887–1987* (Columbia: Missouri Agricultural Experiment Station, 1987); H. C. Knoblauch et al., *State Agricultural Experiment Stations: A History of Research Policy and Procedure*, Misc. Publication 904 (Washington, DC: USDA, 1962).

[46] Deborah Fitzgerald, "Technology and Agriculture in Twentieth-Century America," in *A Companion to American Technology*, ed. Carroll Pursell (Malden: Blackwell, 2005), 69–82.

[47] On the industrialization of agriculture in the United States, see J. L. Anderson, *Industrializing the Corn Belt: Agriculture, Technology, and Environment, 1945–1972* (DeKalb: Northern Illinois University Press, 2009); Deborah Fitzgerald, *Every Farm a Factory: The Industrial Ideal in American Agriculture* (New Haven: Yale University Press); Paul Conkin, *A Revolution Down on the Farm: The Transformation of American Agriculture since 1929* (Lexington: University Press of Kentucky, 2008).

then, to find at the UT-AEC laboratory—which was a state agricultural experiment station—researchers who engaged in projects in which the primary aim was to improve the production of agricultural commodities like soybeans, eggs, and milk. This is exactly the kind of research that state agricultural experiment stations were intended to produce.

But researchers at the UT-AEC Agricultural Research Laboratory also heeded other imperatives: those arising from the nuclear mission of this particular research facility. The laboratory had emerged out of negotiations over the care of a herd of cattle that had been exposed to atomic fallout during the first atomic test at Alamagordo, New Mexico in 1945. The cattle had initially been transferred from New Mexico to the Manhattan Project site in Tennessee—then called the Clinton Laboratories but later renamed the Oak Ridge National Laboratory—where they could be studied by health scientists already in the employ of the Manhattan Project.[48] By 1948, Oak Ridge administrators were looking for a new management regime for the herd. An initial negotiation with UT (which oversaw the TAES) about management of the herd led to an expanded proposal for a far more extensive research program and the construction of the UT-AEC Agricultural Research Laboratory.[49]

The agreement created a new outpost for agricultural science within an established network of eight state agricultural experiment stations. The laboratory was located on the U.S. government's Oak Ridge Reservation, near the national laboratory, but like the other Tennessee experiment stations it was overseen by UT.[50] In other

[48] *UT-AEC Agricultural Research Laboratory* (ref. 1), 3.

[49] TAES, *Sixty-Second Annual Report, 1949* (Knoxville: [University of Tennessee], 1949), 157.

[50] "UT-AEC Research Program," *Tennessee Farm and Home Science*, Apr-June 1954, 3, 10, on 3.

words, this was not a case of practically oriented agricultural and horticultural researchers being invited to collaborate with the so-called basic research team housed at the nuclear laboratory, as was the case at Brookhaven. At the UT-AEC facility, station researchers developed their own agricultural research projects, sometimes but not always with assistance from Oak Ridge National Laboratory staff.

As a result, research at the UT-AEC laboratory tended to be carried out and described in much the same manner as other TAES research. Station reports emphasized that Tennessee farmers would directly benefit as they did in the activities of all of the agricultural stations. "As the atom chasers uncover new information on life processes other Station scientists apply the information to research in their respective fields. And as practical results are determined, county agricultural workers of the Agricultural Extension Service pass along improved practices to farm families…" described one 1954 report.[51] At Brookhaven, by comparison, annual reports emphasized that the Brookhaven researchers themselves were neither conducting agricultural research nor perfecting seeds and plants for release to the market. They were conducing research in genetics, and merely facilitating the application of their findings elsewhere. "The final development of the seed for commercial application is left to the agricultural experimental stations and others," noted one Brookhaven annual report.[52] This is not to say that Brookhaven biologists like Singleton did not aspire to the production of improved crops—they clearly did. In fact, one of the most celebrated products of the plant irradiation research program was a purportedly disease-resistant oat variety that

[51] Ibid., 10.

[52] BNL, "Annual Report, July 1, 1954" (ref. 29), xii, xiii.

had been produced through exposure in the thermal column.[53] Nor does it indicate that the Tennessee researchers did not understand that they were engaged in research that promoted atomic energy. On the contrary. As the 1954 Tennessee station report noted of the experiments at the UT-AEC laboratory, "these tools demonstrate that the atom can be friend rather than foe in our way of life," describing an outcome that was perhaps of more interest to the AEC than to Tennessee farmers.[54] The difference was in the comparative emphasis given to each of these goals at the two sites.

The UT-AEC laboratory was frequently described as filling a particular gap in the expanding portfolio of U.S. atomic program, in that it provided capacity to conduct research using large animals.[55] In addition to facilities for taking care of herds and staff with relevant expertise, the laboratory had specialized apparatus such as a "burro radiation field" where whole-body irradiation of large animals could be carried out. (Figure 5.) The first studies undertaken at the laboratory reflected this specialization, and included studies in farm animals of bomb-radiation effects (i.e., the Alamogordo cattle herd), the metabolism of fission products, the effects of radiation on reproductive

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[53] Calvin Konzak, "Stem Rust Resistance in Oats Induced by Nuclear Radiation," *Agronomy Journal* 46, no. 12 (1954): 401–43.

[54] "UT-AEC Research Program" (ref. 50), 10.

[55] TAES, *Sixty-Second Annual Report* (ref. 49), 158. Westwick argues that because of the "systematicity" of the national laboratories, their research programs developed under competitive conditions that encouraged specialization and discouraged duplication. Emphasizing a unique purpose—like large animal facilities—was evidence of the UT-AEC laboratory's positioning within this larger system. See Westwick, *National Labs* (ref. 8), 10–23.

function, and radioisotope studies of milk production, alongside other work in topics such as soil chemistry and poultry nutrition.[56]

[Figure 5 about here.]

It was not until 1954 that the laboratory incorporated plant investigations into its in-house research activities. Thomas Osborne was brought on that year as an associate plant breeder in the botany department, and he subsequently established a new line of inquiry in plant irradiation and oversaw the installation of plant irradiation equipment. (Figure 6.) The timing of Osborne's hire suggests the growing influence of the radiations mutation program at Brookhaven. By the mid-1950s, the gamma field and associated research was drawing national and international attention, not least because of its promised agricultural payoffs and the tidy fit between these declarations and increased interest in the "peaceful atom." Other researchers across the country had begun to adopt the same research questions and especially the same tools.

[Figure 6 about here.]

Osborne's research career is itself a good example of this trend. Before arriving at Oak Ridge, he had completed his graduate study in the department of agronomy of the State College of Washington, where an active program in mutation genetics flourished after the war. The AEC had supported Osborne's thesis research, a comparative cytogenetic study of the effects of x-rays, radioisotopes, and thermal neutrons on various plants. The aim of that project had been to establish a line of wheat that would combine desirable traits of two different types by "radiation-induced translocations"—essentially an exchange of chromosome segments achieved through irradiation.[57] This

[56] TAES, *Sixty-Second Annual Report* (ref. 49), 161–72.

[57] Osborne to Stadler, 16 Apr 1953, LJS Papers, folder 141.

AEC-sponsored graduate training placed him in an ideal position to take the post in botany at UT-AEC.

Osborne continued a similar pattern of research at Oak Ridge, focusing on the use of radiation to address particular plant breeding needs. Beginning in 1954, he oversaw research on the improvement of annual forage crops, including lespedezas, crimson clover, and vetches. His approaches for each of these included the same techniques: attempts at "ordinary breeding" through hybridization, exposure to gamma rays to produce mutations, and treatment with the plant alkaloid colchicine to generate polyploidy. Osborne seems to have understood the latter two methods as ways to goad more recalcitrant species into improvement. For example, that fall, he exposed thousands of crimson clover seeds to gamma radiation in the hope of finding mutated varieties with traits that would enhance their value as forage plants. As a report detailing the work noted, "The apparent lack of genetic variability in crimson clover, giving little hope of improvement through ordinary breeding, was attacked with colchicine and radiation."[58]

As at Brookhaven, these initial studies precipitated further innovations, both in equipment and in research programs. The following year, the station constructed a new plant-and-seed irradiation facility whose mechanical operation recalled that of the Brookhaven gamma field. Initially, the burro field had served as a site for gamma-ray treatment of plants. But this could not be used in administering high-intensity gamma rays—a capability needed to treat seeds in particular—and so Osborne and his colleagues designed and built the new unit for this use especially. It consisted of two

[58] TAES, *Sixty-Seventh Annual Report, 1954, of the Tennessee Agricultural Experiment Station* (Knoxville: University of Tennessee, 1954): 21–22.

concrete-block buildings sixty-four feet apart. One contained a radioactive cobalt source housed in stainless steel and the other functioned as a control house. From the control house, a researcher could, by means of a hand crank, raise or lower the cobalt source in the opposite building from the bottom of a water-well in which it was kept for shielding. Small objects such as seeds were placed in a plastic cylinder that would be completely surrounded by the cobalt source when it was raised, thereby receiving the highest levels of gamma ray exposure; alternatively, experimental materials could be placed on a circular wooden platform that rotated around the outside of the source.[59] (Figure 7.)

[Figure 7 about here.]

The in-house research program that relied on this irradiation facility involved studies of the genetic and physiological effects of radiation on plants along with efforts aimed at making induced-mutation breeding practical, such as determining the appropriate dose of radiation for various types of seed.[60] These activities tended to be described using a formula typical for agricultural station research: any research undertaken at the station, no matter how removed from everyday farming it seemed, would eventually inform agricultural practices and therefore benefit farmers. These were well-rehearsed lines, certainly, and their being linked to nuclear science meant that they also rehearsed the AEC position on funding projects like Osborne's, which declared that peaceful deployment of atomic energy would lead to a better, more bountiful future. But to dismiss them as mere rhetorical flourishes would be to overlook the ways in which breeders at UT-AEC did hope that nuclear technologies would help

[59] T. S. Osborne, and A. O. Lunden, "The Cooperative Plant and Seed Irradiation Program of the University of Tennessee," *The International Journal of Applied Radiation and Isotopes* 10, no. 4 (1961): 198–209.

[60] Ibid.

them solve specific and sometimes pressing concerns arising within the agricultural system of which they were a part.

A case in point is Osborne's participation in soybean investigations, one of the more extensively publicized plant irradiation studies associated with the UT-AEC laboratory. In 1954 a novel threat to soybeans—*Heterodera glycines*, the soybean cyst nematode—had appeared in North Carolina. Despite efforts to contain the spread of the worm, by 1956 it had established itself across the American South, announcing its arrival on farms in stunted, yellowed soybean plants that offered poor yields. Concerned about the future status of soybean cultivation, researchers at Southern agricultural experiment stations began to study means of controlling the damage. TAES was no exception, and Osborne numbered among researchers whose research included solutions to the nematode outbreak. His approach, unsurprisingly, was to expose different varieties of soybean to gamma-ray irradiation in the hopes of inducing disease-resistance. As Osborne declared of this work, "any desirable attributes found will be bred into an improved variety… then released to Tennessee farmers."[61] By 1962, Osborne's radiation-based improvement work included, in addition to soybeans, large-scale plantings of irradiated cotton, fescue, and orchardgrass.[62]

Osborne's colleagues also participated in the induced-mutation research, and similarly directed their attention to projects that were of central concern to Tennessee farmers. For example, Leander Johnson and James Epps of the Knoxville experiment station turned to induced mutation after numerous failed attempts to develop cotton

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[61] H. S. Reed and T. S. Osborne, "Soybean Research in Tennessee," *Soybean Digest* 19, no. 5 (1959): 18–19, on 19.

[62] TAES, *Progress of Agricultural Research in Tennessee, 1961–1962, 74th and 75th Annual Reports of the Tennessee Agricultural Experiment Station* (Knoxville: University of Tennessee, 1962), 37.

resistant to a harmful fungal wilt. In search of a new approach they exposed cotton seeds to gamma radiation, hoping to produce mutations that conferred disease resistance.[63] In a later cotton-breeding project, the researcher Milton Constantine used a portable gamma ray machine, containing a cobalt-60 source, to irradiate cotton bolls after fertilization. This technology had been developed by Singleton along with physics and engineering colleagues during his tenure at Brookhaven before appearing in Tennessee cotton fields.[64] Constantine hoped the device would help him to produce a long sought-after hybrid of American upland cotton and Sea Island cotton, one that would combine the high quality fiber of the latter with the environmental adaptability (and therefore extensive cultivation range) of the former.[65] In this case, he did not hope that irradiation of the hybrid cotton would produce a mutation, but rather that it would lead to translocations, in which there would be an exchange of segments of chromosomes derived from each of the parent cotton varieties within the cells of the developing seed. If successful, the method would suggest a way to solve similar hybridization problems in other species, transforming the portable cobalt-60 device into a reliable technology for agricultural breeding.[66]

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[63] Leander Johnson and James M. Epps, "Radiation Tests Look to Wilt Resistant Cotton," *Tennessee Farm and Home Garden*, July–Sept 1957, 4.

[64] O. A. Kuhl, W. R. Singleton, B. Manowitz, "Cobalt-60 Field Irradiation Machine," *Nucleonics* 13, no. 7 (1955): 42.

[65] TAES, *Progress of Agricultural Research* (ref. 62), 36–37.

[66] *UT-AEC Agricultural Research Laboratory* (ref. 1), 38; "Seeks Cross That Will Stay Crossed," *Kingsport News*, 17 July 1961, 2.

The radiation facilities at the UT-AEC Agricultural Research Laboratory were also used to treat seeds and plants for researchers at institutions across the South.[67] This outreach work had been initiated with the approval of the AEC's Advisory Committee on Biology and Medicine, and partly in response to a presentation that Singleton had given to Southern agriculturists on the potential benefits of radiation to breeding. It was obvious to the committee that the UT-AEC facilities offered a chance to involve many more Southern agricultural researchers in nuclear-related science—an obvious good.[68] The resulting program resembled its counterpart at Brookhaven. Collaborators could use the radiation facilities *gratis*, if they agreed to collaborate with on-site researchers by sending in reports on their results; subsequent investigation of radiation effects would have to be the responsibility of the cooperating researcher. Those who wished to have seeds or other plant material exposed to neutron radiation could arrange to have this done in the nuclear reactor at Oak Ridge, though they had to pay a fee for the service.[69] By 1961 more than fifty researchers had participated in the cooperative program. They represented eighteen different institutions, almost all of which were other agricultural experiment stations of the South.[70] As in the case of the Brookhaven cooperative program, it is likely that most hoped to discover useful new traits and types. This is certainly how Osborne perceived their hopes, describing the typical cooperator

[67] TAES, *Sixty-Eighth Annual Report, 1955, of the Tennessee Agricultural Experiment Station* (Knoxville: University of Tennessee, 1955), 70–71.

[68] Minutes for the Meeting of the Advisory Committee for Biology and Medicine, Oak Ridge National Laboratories, Oak Ridge, Tennessee, 5–7 May 1955, DOE/NV, accession no. NV0411745; Shoup to Roth, 19 May 1955, DOE/NV, accession no. NV0706973.

[69] Osborne and Lunden, “Plant and Seed Irradiation Program” (ref. 59), 199.

[70] Ibid., 203–05.

as someone interested in "an automatic, self-adjusting, mysterious, and glamorous system whereby new varieties would somehow spring suddenly into being, needing only to be named and released by the victorious breeder."[71]

The UT-AEC staff gathered data—or attempted to—on the outcomes of these irradiations in order to compile a chart of the "relative sensitivities" of the various species and seeds to radiation exposure or, as it was also described, their "radioresistance."[72] This, too, was pitched as a project essential for transforming radiation into an effective and reliable tool for practical breeders. The data produced by cooperators, compiled and analyzed at the station, would be used to inform breeders about the intensity and duration of radiation to be used for any particular crop in order to achieve the desired balance of genetic change and seed survival. The hope was that this would directly facilitate the uptake of induced-mutation breeding.[73] Unfortunately, this comparative research did not interest cooperators, most of whom dragged their feet on returning the paperwork with their observations.[74]

The Tennessee researchers retooled existing experimental technologies (like field irradiation devices) and research programs (like cooperative irradiation), first developed at Brookhaven to promote the use of atomic technologies, to better suit the constraints and aims of their own technological context. Most telling of their differing aims was the gap between AEC rhetoric and the ambitions of mutation breeders.

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[71] Thomas S. Osborne, "Regional and National Program on Use of Irradiation in Plant Breeding," in *Southeastern Seminar on Atomic Progress in Agriculture* (Clemson, SC: Clemson College, 1961), 36–43, on 42.

[72] Osborne and Lunden, "Plant and Seed Irradiation Program" (ref. 59), 208–09.

[73] "Planters Now Can Predict How Well Seeds Will Grow," *Kingsport News*, 1 Dec 1958, 2.

[74] Osborne and Lunden, "Plant and Seed Irradiation Program" (ref. 59), 208.

Although AEC officials and others touted atomic technologies as likely to "revolutionize" agricultural production, American plant breeders at state agricultural experiment stations and the USDA did not use atomic resources in ways likely to upend the established agricultural system. Breeders like Osborne and his colleagues attempted to use atomic technologies to produce crop varieties that were hardy and easily cultivated, that would survive the disease and pest outbreaks common in genetically homogenous monocropped fields, and that promised above all higher yields of key economic products.

Viewing atomic technologies as one set of tools among many, they made definitive but circumscribed claims about their use. Although Osborne was a vigorous promoter of the application of atomic energy in plant breeding, extolling its benefits in the experiment station's magazine *Tennessee Farm and Home Science* and elsewhere, he also emphasized that the results would not be immediate. New types created through induced mutation would have to be crossed back to standard varieties or otherwise developed by breeders for a number of years.[75] Of course, lest readers worry about whether this called the whole enterprise into question, Osborne issued a reassuring statement: The radioactive sources that had been made available to growers throughout the South, including those provided at the UT-AEC laboratory, were "potential contributors to agricultural improvements for the benefit of millions of people in several states."[76] He was clearly aware of his obligations to both agricultural and atomic productivity.

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[75] T. S. Osborne, "Radiation and Plant Breeding," *Tennessee Farm and Home Science*, Apr–June 1957, 8.

[76] T. S. Osborne, "Atomic Tools Help Plant Breeders," *Tennesee Farm and Home Science*, April-June 1956, 3, 9, on 9.

The UT-AEC plant-breeding program, which continued into the 1960s, used methods and technologies similar to those innovated at Brookhaven National Laboratory; however, its staff directed these towards more immediate practical achievements than did their Brookhaven counterparts. In this the UT-AEC researchers were influenced perhaps by the attention given to the Brookhaven cooperative program and their claims to some successes by the early 1950s. They were also influenced by their particular institutional context, that is, from the establishment of the program as one part of network of agricultural experiment stations rather than a division within Oak Ridge National Laboratory itself. As such, the mutation-breeding program was, like other experiment station research, carried out and advertised with an eye to the needs of Tennessee farmers and with attention given to solving pressing local agricultural problems. Poised at the intersection of two technological systems, one dedicated to atomic energy and the other to food production, the UT-AEC researchers found themselves pursuing two distinct aims. On the one hand their efforts were meant to boost agricultural production. They hoped to produce improved crops for Tennessee agriculturists and to make radiation exposure a more useful tool for breeders. On the other hand, their efforts also supported the development of atomic energy and the agenda of "Atoms for Peace" by highlighting for farmers and consumers the benefits that would accrue from atomic-aided research.

Other U.S. agricultural institutions followed a similar path from the late 1950s onward. One telling case is that of the Florida Agricultural Experiment Station, where the AEC supported construction of the station's Cobalt-60 Irradiation Facility. Built in 1958, the five-acre field boasted a 6400-curie source that would be used to study a whole range of agricultural applications of radiation.[77] Projects planned for the facility at the time of its construction included the sterilization of fruits and vegetables, irradiation of meat and animal feed, in addition to induced-mutation breeding and associated genetic research. Within the latter category, all departments were reported as eager to participate: "The Agronomy department will use radiation to induce mutations in economic crops. The Ornamental Horticulture department will look for radiation-induced changes that produce new horticultural varieties… The Fruit Crops department will seek to obtain radiation-induced mutations for chilling requirement and cold resistance in peaches. The Vegetable Crops department will look for disease resistant mutations in peas and beans."[78] All were hoped-for payoffs that would surely aid Florida agriculturists and horticulturists, while also serving as evidence of the beneficence of the peaceful atom.

The intersection of the atomic and agricultural technological systems did not always require an undertaking as significant as the construction of a dedicated irradiation facility. In fact, it more often meant simply a researcher or group of researchers who carried out atomic-related investigations amidst the usual gamut of agricultural studies and experiments. But it is likely that within these programs, too, researchers responded to the machinations of the two distinct technological systems in which they were embedded, using the technologies generated by the atomic research system in pursuit of the goals long embraced by the agricultural research system.

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[77] Howard J. Teas, "The Use of Cobalt-60 Gamma Radiation in Ornamental Horticulture," *Florida State Horticultural Society* 71 (1958): 450–52; Howard J. Teas, "Station Installs Cobalt Irradiator," *Sunshine State Agricultural Research Report* 3 (1958): 4–5, on 4.

[78] Teas, "Station Installs Cobalt Irradiator" (ref. 77), 4.

[FIRST LEVEL HEADING] THE NATURE OF INNOVATION

The intersection of the nuclear and agricultural technological enterprises gave rise to, among other things, the use of elaborate, expensive, and hazardous techniques like cobalt-60 irradiation to tackle typical concerns of crop breeders, and to the promotion of such techniques as the solution to agricultural problems across the American South and elsewhere in the United States in the 1950s and 60s. Only when one considers the imperatives of innovation in these technological systems—one committed to the production of atomic innovations and another concerned with the production of (among other things) innovations in crop plants—and the movement of innovations like cobalt irradiation devices and cooperative programs across them, is it possible to fully appreciate the origins and aims of atomic agricultural research such as that pursued by the otherwise atypical Tennessee plant breeder Thomas Osborne. In fact, this is a useful way to understand Osborne's career as well, which in the 1950s and 60s carried him from studying the possible uses of radiation in breeding to working as a mutation breeder to promoting the ideas and techniques of mutation breeding. His career emerged from the opportunities created at the nexus of technological systems.

In many respects, this claim will hardly surprise historians of science and technology who are familiar either with the historiography of Cold War science or of agricultural genetics, areas in which the influence of technological aims on the trajectories of research have been heavily investigated.[79] But there is another general

[79] In physics, examples of such research abound, including most famously the work of Paul Forman but continuing to present; see Paul Forman, "Behind Quantum Electronics: National Security as Basis for Physical Research in the United States, 1940-1960," *Historical Studies in the Physical and Biological Sciences* 18, no. 1 (1987): 149–229 or, for recent reflections on this history and historiography, Naomi Oreskes and John Krige, eds., *Science and Technology in the Global Cold War* (Cambridge: MIT Press, 2014).

lesson to draw from this history, which arises from thinking about this influence of technological imperatives on research through the lens of large technological systems. Such systems create opportunities for unexpected and innovative research programs (such as when corn breeders to gain access to nuclear reactors) and for enterprising researchers to forge novel career trajectories (such as cooperative seed irradiator or mutation breeder). What's more, this may be especially true in those situations where large technological systems intersect but do not merge.

Many early explorations of large technological systems treated these as distinct entities, whether electrical grids, railroad systems, or communications networks.[80] Of course, in practice, technological systems intersect and entangle all the time: one need only think of the incorporation of nuclear technologies with established systems of energy production and delivery via the creation of nuclear plants, or the interweaving of computer networking and communications technologies with transportation

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The relationship of early genetics to agriculture and eugenics is an equally rich area of scholarship; see, e.g., Barbara A. Kimmelman, "A Progressive Era Discipline: Genetics at American Agricultural Colleges and Experiment Stations, 1900–1920" (Ph.D. dissertation, University of Pennsylvania, 1987); Diane B. Paul and Barbara A. Kimmelman, "Mendel in America: Theory and Practice, 1900–1919," in *The American Development of Biology*, ed. Ronald Rainger, Keith R. Benson, and Jane Maienschein (Philadelphia: University of Pennsylvania Press, 1988), 281–310; Garland E. Allen, "The Reception of Mendelism in the United States, 1900–1930," *Comptes Rendus de l'Académie des Sciences - Series III - Sciences de la Vie* 323, no. 12 (2000): 1081–88.

[80] See, e.g., contributions to Renate Mayntz and Thomas P. Hughes, eds., *The Development of Large Technical Systems* (Boulder: Westview, 1988). This continues to be the dominant form of studying such systems; see summary in Paul N. Edwards, "Infrastructure and Modernity: Force, Time, and Social Organization in the History of Sociotechnical Systems," in Thomas J. Misa, Philip Brey, and Andrew Feenberg, *Modernity and Technology* (Cambridge: MIT, 2003), 185–225, on 198–99.

infrastructure in the production of real-time data about mass transit on hand-held mobile devices. A handful of more recent studies better characterize this entanglement, describing the interlinking of different technological systems into sprawling infrastructures or internetworks oriented towards new goals such as global shipping or communications.[81]

To date, research that looks at how technological systems interact has focused on cases where systems are linked to achieve a common purpose, as in the examples described above. But what about cases in which two systems remain largely distinct, oriented not to the same goal but to different ones? As I described, the application of nuclear technologies in plant breeding arose at sites where the systems dedicated to the advancement of nuclear development and the expansion of agricultural production met one another. But there was never a major infrastructure for nuclear agriculture in the United States, only a loose assemblage of similar research programs flourishing at a particularly favourable moment in particularly favourable places.[82] Most studies of

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[81] e.g., Paul N. Edwards, "Y2K: Millennial Reflections on Computers as Infrastructure," *History and Technology* 15, no. 1–2 (1998): 7–29; Greg Downey, "Virtual Webs, Physical Technologies, and Hidden Workers: The Spaces of Labor in Information Internetworks," *Technology and Culture* 42, no. 2 (2001): 209–35; Paul N. Edwards, *A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming* (Cambridge: MIT, 2010); Matthew W. Heins, "The Shipping Container and the Globalization of American Infrastructure" (Ph.D. dissertation, University of Michigan, 2013).

[82] More lasting infrastructure for nuclear agriculture did develop in other parts of the world, especially with the encouragement of the International Atomic Energy Agency (IAEA), working jointly with the FAO. On nuclear agriculture in Europe, see Zachmann, "Risky Rays" (ref. 4) and Zachmann "Peaceful Atoms in Agriculture" (ref. 40). For an overview of the continued use of nuclear techniques in contemporary agricultural research, see the website of the Joint FAO/IAEA Programme on Nuclear Techniques in Food and Agriculture, at http://www-naweb.iaea.org/nafa/index.html (accessed 7 Oct 2015).

internetworks and infrastructures, although relevant to this and similar cases, seek to capture different dynamics: the creation of enduring systems. Even the study of "second-order" technological systems—those that are constructed out of the components of existing large technological systems, as in the case of an international organ donation system relying on existing transportation, communications, and medical infrastructures—still take as their starting place the need to explain some emergent system-level entity.[83]

But is this the only way in which large technological systems meaningfully interact? The cases presented here suggest not. I have considered moments of innovation as well as the mobility of specific innovations within and between systems, a route that does not presuppose the creation of a successful infrastructure or second-order technological system and as such allows for the exploration of other kinds of system interaction. This in particular suggests a way of seeing and understanding contingency within large technological systems—an aspect that often falls out of consideration of these—for it is a reminder that such systems are not worlds unto themselves but embedded in still larger agglomerations of people, machines, and ideas. It also suggests a route towards better characterizing scientific research that arises and flourishes (even if only for a time) at the conjunction of systems. To take other cases from the history of the plant sciences, it may be a means of differently understanding

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[83] On second-order technological systems, see Ingo Braun and Bernward Joerges, "How to Recombine Large Technical Systems: The Case of European Organ Transplantation," in Jane Summerton, ed., *Changing Large Technical Systems* (Boulder: Westview, 1994), 25–52. These are also described in Erik van der Vleuten, "Infrastructures and Societal Change. A View from the Large Technical Systems Field," *Technology Analysis & Strategic Management* 16, no. 3 (2004): 395–414.

how and why flower and vegetable seeds came to orbit the Earth in shuttles and satellites, or the emergence of satellite-based studies of global vegetation.[84]

Interest in mutation breeding did not last long in the United States. By the mid-1960s, the wave of enthusiasm that had prompted the establishment of research facilities and breeding programs was over. There likely were a number of factors behind this shift, from burgeoning interest in other means of genetic manipulation to continued failure to produce convincing results via induced mutation. Although for a time the creation of a lasting infrastructure to support the application of nuclear technologies in American agriculture had seemed possible, it ultimately failed to materialize. In the meantime, however, the intersection of these two technological systems at sites like Brookhaven and the UT-AEC Agricultural Research Laboratory created spaces for the production of novel research and new innovations, and for the making of unusual scientific careers—none of which can be completely understood without understanding the dynamics of the systems in which they were embedded.

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[84] Helen Anne Curry, "Tomato Seeds in Space: NASA Outreach and Science Education in the Shuttle Era," *Endeavour* 34, no. 4 (2010): 173–80; Robert Buitenwerf, Laura Rose, and Steven I. Higgins, "Three Decades of Multi-Dimensional Change in Global Leaf Phenology," *Nature Climate Change* 5 (2015): 364–68.